

# **APPENDIX 1**

# **800 MHz Interference Mitigation**

## *Technical Discussion*

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## **1. Introduction**

The above-named carriers formed a working group (WG) to address the technical issues related to potential interference into 800 MHz public safety radio systems.

The WG is comprised of engineers from several major cellular and digital SMR operators. In this document, we refer to 800 MHz cellular and digital SMR services collectively as the Commercial Mobile Radio Service (CMRS). The companies represent all major air interface technologies currently deployed by CMRS carriers in the 800 MHz band: CDMA, TDMA, iDEN, and analog.

The WG's tasks have included: 1. Identifying the mechanisms that are the most likely causes of interference to public safety; 2. Analyzing proposed solutions and identifying benefits and drawbacks of those solutions with regard to interference mitigation; 3. Constructing a long-term plan that the WG believes is the most effective method of reducing or eliminating public safety interference caused by 800 MHz digital SMR (primarily Nextel), and, to a much more limited extent, interference caused by cellular.

Section 2 of this document discusses the apparent causes of interference to public safety systems from CMRS operations. Section 3 summarizes available performance data for public safety portable radios. Section 4 provides summary data on performance specifications for 800 MHz CMRS transmitters. Section 5 discusses various 800 MHz reband proposals that are presented in the FCC NPRM, and provides the WG's assessment of the interference mitigation potential of each. Section 6 discusses the overall strategy that would best alleviate interference to public safety due to Nextel and, to a lesser extent, other CMRS operations.

## **2. Interference Mechanisms: Background**

Each WG participant company has experienced isolated reported cases of interference into public safety systems. In each case, the reported interference was manifest as an inability of a public safety portable radio to receive communications from its associated base station. The interference occurred in a small number of well-defined geographic areas that were in the vicinity of SMR or cellular towers and were a large distance from the public safety base station tower.

In the majority of interference cases, the WG member companies have determined that the predominant contributor to the interference was Nextel.

### *2.1 Interference Factors*

The interference is the result of a combination of factors:

1. The lack of filtering within the public safety portable radios that would effectively remove CMRS transmissions from the receive path.
2. The spectrum allocations at 800 MHz that make the wide filtering of the public safety radios a necessity and that create interleaving of SMR and public safety channels.
3. The strong signal strength of the CMRS transmissions in the immediate vicinity of the CMRS towers.
4. The relatively weak signal strength of the public safety base station transmissions due to the general architecture of the public safety radio systems.

Each of these factors is discussed in greater detail in the following subsections. §2.2 discusses the root causes of the public safety interference in light of the four contributing factors.

#### 2.1.1 Public Safety Portable Radio Filtering

The public safety portable radios must presently receive public safety base station signals anywhere in the 18 MHz wide frequency range of 851 – 869 MHz. Early in the receive chain of the radios (the “front end”), signals in this range must be passed with a minimum amount of loss, meaning that front-end filters must be designed to pass this range of frequencies with as little attenuation as possible. Outside of this range, the transition region between the point at which the filters provide no attenuation and the point at which they begin to provide significant attenuation (referred to as the filter roll-off) is several MHz wide. Filters that have fast roll-off are always desirable, but they are generally costly and physically large, and therefore unsuitable for portable radios.

Based on our understanding of the performance specifications of the predominant manufacturer of portable public safety radios, we generally find that the portable radios include either stripline or ceramic pre-selector filters with 3 dB bandwidths of approximately 50 MHz. Based on these general specifications, we expect the filter roll-off at the upper end of the public safety band (adjacent to the cellular base transmit band) is roughly 3 dB of attenuation over 17 MHz (-3 dB @ 886 MHz), meaning that the pre-selector filters have very little attenuation across the entire A-side cellular band at 869 – 880 MHz. Consequently, the public safety portable radios allow all of the signals from interleaved operations (for example, digital SMR) in the 851 – 869 MHz band, plus a large fraction of the signals from the cellular base transmit band, to reach the low noise amplifier, which is the first amplifier in the receive chain.

#### 2.1.2 Spectrum Allocations

The wide filtering of the public safety portable radios is a result of having to operate across the entire 851 – 869 MHz band. Included in this frequency range are other allocations, namely the other Part 90 services Business, Industrial/Land Transportation, and SMR, operating on interleaved channels with public safety. Immediately above this frequency range is the base station transmitter band for the cellular A-side operators. This interleaving and adjacency produces many strong signals that are not filtered by the public safety portable radios. If public safety radios operated in their own segment of 800 MHz, with no interleaved operations, then their filters could be improved to better filter out adjacent band operations. However, due to finite filter fall-off and the economics and

size/weight constraints for portable radios, a significant guard band between public safety operations and other systems would be required. Determining the specific size of such a guard band (in MHz) would be very complex, if not impossible. The exact size required to successfully minimize interference would depend on many factors, including the architecture, power, modulation type, and geographic distribution of the adjacent operations.

### 2.1.3 Strong CMRS Signals

CMRS operators generally operate capacity-constrained systems. To increase capacity, the operators attempt to deploy as many cells as needed, and to re-use the same frequencies on non-adjacent cells. To mitigate interference between cells, the footprint of each cell is localized as much as possible by a variety of methods, including reducing power, using antennas mounted at lower heights, and/or tilting the base station antennas downward (downtilting). This type of architecture is often referred to as “low-site low-power” design, or “cellular-like” architecture. Generally, due to the number of cells and the frequency re-use techniques, the cellular systems often have relatively strong “on-the-street” signal strengths, especially in the vicinity of the base station sites.

### 2.1.4 Weak Public Safety Signals

In contrast to the CMRS systems, public safety systems are typically noise-limited systems. In essence, the typical public safety radio system uses as few base stations as possible, and relies on sensitive mobile and portable radios to be able to hear the base station signals out to a large distance. This architecture is sometimes referred to as “high-site, high power” design. Generally, the typical “on-the-street” signal strength from a public safety base station is significantly lower than the typical “on-the-street” signal strength of the CMRS systems.

## *2.2 Causes of Interference*

*The predominant interference mechanism is overload of the front-end amplifiers of the public safety portables.* Overload produces desensitization (“desense”) and intermodulation interference (“intermod”) within the public safety portable. This interference is created *inside* the portables. A third, but significantly smaller, interference contribution is CMRS out-of-band emissions that are emitted within the receive channel of the public safety portable radio.

Desense and intermod will occur whenever the public safety portable radio receives strong signals within its passband (the passband is the range of frequencies that is passed by the front-end filter). The strong signals do not have to be close in frequency to the public safety channels; they only have to be within the passband of the public safety radio. For example, even if the public safety channels are isolated to the lower portion of the 800 MHz band, and if SMR and cellular allocations were placed at the top end of the band, the public safety radios would still be affected by desense and intermod if their front-end filters remained the same as they are today. Desense will not be reduced simply by increasing the frequency separation between desired and interfering signals. New filters that take advantage of the frequency separation must be installed.

Intermod may be modestly reduced by the small amount of frequency separation that could be achieved by relocating public safety systems within the 800 MHz band, without the installation of new filters in public safety radios. This modest reduction in intermod will prove to be short-lived, though, as 800 MHz licensees continue to build out their systems, effectively reversing any improvements attained by relocation of public safety. Furthermore, the introduction of new filters in conjunction with relocating public safety systems within 800 MHz would present a trade-off for those systems. While new filters may provide additional mitigation of the intermod interference, the use of filters with higher insertion loss that further attenuate the public safety frequencies reduces the coverage provided by existing public safety systems.

Desense and intermod are related interference mechanisms, since both are created by overload of the front-end amplifier of the public safety radios. Thus, both are reduced significantly when the strength of the non-public safety signal is reduced.

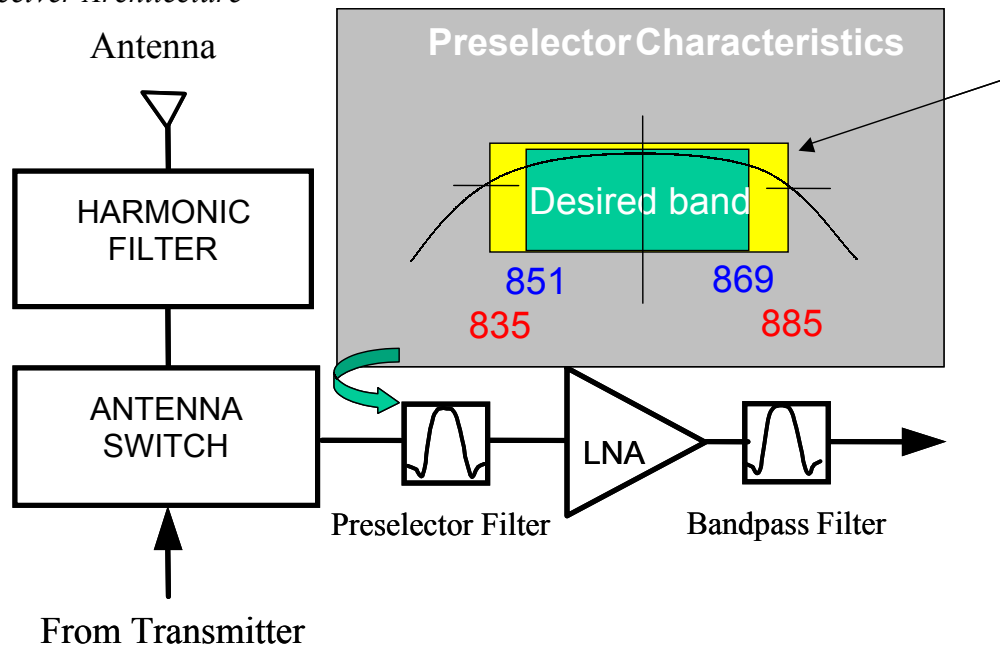
Out-of-band emissions from CMRS signals are another potential source of interference to public safety communications. All transmitters produce undesired signals that are emitted outside of the intended channel of transmission. These undesired signals include: (i) spurious emissions, which are defined as harmonics and other signals that occur far removed from the intended transmit frequency, and (ii) out-of-band emissions, which by definition occur at frequencies closer to the intended transmit frequency and are a result of the modulation process. The combination of spurious and out-of-band emissions are known as unwanted emissions. Unwanted emissions that occur on public safety frequencies cannot be filtered by the public safety radios, since they are occurring on frequencies that the public safety radio is attempting to receive. Unwanted emissions can only be reduced by additional filtering on the interfering transmitter. Because out-of-band emissions are at very low power levels compared to the fundamental signal, a receiver must be very close to a CMRS transmitter before out-of-band emissions become an interference factor. At such close distances however, desense and intermod would be the predominant interference mechanisms.

### **3. Public Safety Portable Radio Performance Specifications**

The following sections of this document address performance specifications and interference mechanisms in technical detail.

Limited information on the performance specifications of public safety portable radios is available to the CMRS industry. Only partial intermodulation performance specifications on some models of Motorola radios have been obtained. The data are extracted here.

### 3.1 Receiver Architecture



**Figure 3.1.1:** Public safety portable radio architecture (based on Motorola presentation).

Referring to Fig. 3.1.1, beginning with the antenna:

- The harmonic filter reduces the amplitude of harmonic spurious emissions transmitted by the radio.
- The antenna switch switches the antenna/harmonic filter from the receiver chain to the transmit chain when the push-to-talk button is pressed. Both the harmonic filter and antenna switch have no filtering action specific to the 800 MHz band, but do add insertion loss, which attenuates both desired and undesired signals and adds to the receiver noise figure.
- The preselector filter allows the 851 – 869 MHz band to pass, with 3 dB points at 835 and 885 MHz (50 MHz 3 dB bandwidth). It is the first band-specific filter in the receive chain. Besides filtering, it also adds insertion loss and increases the noise figure.
- The low noise amplifier (LNA) is the first amplifier in the receive chain, and is the component that plays the biggest role in desense and intermod performance. It amplifies all of the signals that pass through the preselector filter, including public safety, SMR and cellular.
- A second bandpass filter is added after the LNA, where the signal is stronger and additional insertion loss has less of an impact on receiver sensitivity.

### 3.2 Preselector Filter

The following information applies to Motorola's stripline design used in its public safety portable radios.

<b>Poles</b>	3
<b>Insertion Loss</b>	2.5 dB
<b>Bandwidth (3 dB)</b>	50 MHz
<b>3 dB Points</b>	835/885 MHz
<b>20 dB Points</b>	Not Provided
<b>Approximate Q (<math>f_0/\Delta f_{3dB}</math>)</b>	17.2
<b>Package Dimensions</b>	440 x 415 x 80 mil

**Table 3.2.1:** Motorola public safety portable radio preselector filter specifications

### 3.3 Desense/Low Noise Amplifier

The effect of desense is quantized by its impact on the amplifier's power budget. In essence, when a strong signal is introduced into the LNA, the LNA uses most of its available power to amplify the stronger signal. When the input signal exceeds a certain level, there is insufficient power available to produce a proportionately amplified output, an effect called gain compression. The LNA performance is usually specified by the 1 dB gain compression point, which is the input signal level at which output signals are reduced in power by 1 dB relative to the expected level. For example, for an amplifier with a nominal 10 dB gain, the 1 dB compression point would be the input signal level for which the achieved gain of the amplifier is only 9 dB due to power budget limitations. No gain compression figures were available to the WG for public safety portable radios.

### 3.4 Intermodulation Performance/Low Noise Amplifier

The intermodulation (IM) performance is characterized by the IM ratio (*IMR*). The 3<sup>rd</sup>-order intermod power equals the noise floor when the input interference power is at a level of *IMR* dB above the reference sensitivity  $I_{ref}$ . For example, the Motorola specifications state an *IMR* of 73 dB and a reference sensitivity of -119 dBm for a 12 dB SINAD, so that the output 3<sup>rd</sup>-order IM power reaches a level of -123 dBm (the receiver noise floor) when the interference is at a level of -46 dBm.

<b>Input 3<sup>rd</sup>-order Intercept (IIP<sub>3</sub>)</b>	3 dBm
<b>Reference Sensitivity (<math>I_{ref}</math>)</b>	-119 dBm (12 dB SINAD)
<b>IM Ratio (IMR)</b>	73 dB
<b>Noise Floor</b>	-123 dBm

**Table 3.3.1:** Motorola public safety radio intermod performance.

#### 4. CMRS Base Station Transmitter Out-of-Band Emission Specifications

Cellular and SMR base stations are required to meet or exceed the following out-of-band emissions performance specifications:

<b>SMR</b>	-80 dBc or -13 dBm per 25 kHz*, whichever is the lesser attenuation	47 C.F.R. § 90.669
<b>Cellular</b>	-60 dBc or -13 dBm per 30 kHz*, whichever is the lesser attenuation	47 C.F.R. § 22.917

\* The FCC rules do not specify the measurement bandwidth;  
it is assumed equal to the allotted channel bandwidth

**Table 4.1:** Out-of-band emission limits for SMR and cellular base stations.

Out-of-band emissions generally fall off with frequency separation. Because of this, transmitters that are closer in frequency to public safety (for example, the interleaved Nextel channels) are a much larger contributor to out-of-band emissions that are received in the public safety radios. Cellular transmitters, which are farther removed in frequency from public safety and are not interleaved with public safety, are a much smaller source of out-of-band emissions interference than Nextel.

#### 5. Proposals for Re-Banding the 851 – 869 MHz Band

Multiple proposals for rebanding the 800 MHz band have been proposed by various entities. Each plan should have as the primary goal reducing interference to public safety radio systems due to CMRS operations.

This section sets forth a framework for analyzing each proposal in the FCC's *Notice of Proposed Rulemaking* (and others that may be proposed) for impact on public safety interference in light of the public safety radio performance specifications and known interference mechanisms discussed in §§2 – 4.

##### 5.1 Interference Mitigation Factors

###### 5.1.1 Receiver Overload

Each reband proposal is discussed with respect to reducing receiver desense. The only method of reducing desense is to move the interfering signals outside of the passband of the public safety radio's preselector filter. *Moving the public safety frequency allocation and the interfering frequency allocation farther apart spectrally, without moving the interfering frequency allocation outside of the public safety radio passband, will have no effect on reducing desense.* For purposes of this analysis, it is assumed that existing public safety radios will continue to be used.

###### 5.1.2 Intermodulation

The intermodulation performance of each rebanding proposal is analyzed in terms of the likelihood that intermodulation products from the CMRS services will fall within the rebanded public safety frequency allocation. The analysis takes into consideration whether the intermodulation products are produced by a single CMRS interferer (for example, SMR), or whether the products are produced by a mix of two CMRS interferers (for example, SMR mixing with A-side cellular). The supposition is that intermodulation

interference that is caused by a single party is easier to rectify and coordinate than intermodulation interference that must be reconciled among two or more possibly competing parties. Only third-order mixing products between two carrier frequencies are considered.

#### 5.1.3 Out-of-Band Emissions

The rebanding proposals are judged upon the relative impact of out-of-band emissions from CMRS carriers on interference into public safety. Since out-of-band emissions fall off rapidly with frequency separation, greater frequency separation between public safety and CMRS will improve out-of-band emissions interference. Generally, if a public safety portable is sufficiently close to receive significant out-of-band emissions from a CMRS transmitter, desense will be the larger problem.

#### 5.1.4 Disruption, Time to Implement, and Cost

This criterion considers factors that would influence how difficult, costly, and time-consuming each rebanding proposal would be. Included in the factors are the impacts of relocation, new equipment purchases, and the potential loss of customers or services.

### *5.2 Baseline Allocation*

The present allocation is used as a baseline.

- Desense: The interleaved channel allocations between public safety and SMR providers, combined with the immediate adjacency of the public safety allocation with cellular A block, make overload a certainty with the present allocation and public safety filter specs of which we are aware.
- Intermod: The present allocation, with public safety channels dispersed throughout the 851 – 869 MHz band, allows intermod products from and between multiple services to potentially interfere with public safety channels.
- Out-of-band emissions: Some public safety channels (the NPSPAC channels) are immediately adjacent to the cellular allocation. Others are immediately adjacent to SMR allotments. The adjacencies create allow higher levels of out-of-band emission interference than would occur if the public safety channels are moved farther away from CMRS. Out-of-band emission interference is not a significant contributor to the interference problem, however.
- Disruption: Since no rebanding is applicable, no disruption or cost associated with rebanding is created.

### *5.3 Nextel Proposal*

Under the *Nextel Proposal*, two separate but adjacent contiguous channel blocks would be created in the 800 MHz band. The upper 16 MHz block would be reserved for digital SMR at 816-824 MHz and 861-869 MHz. The lower 20 MHz block at 806-816 MHz and 851-861 MHz would be reserved for public safety, although the need for a guard band on the downlink between digital SMR and public safety may reduce the proposed block to 18 MHz or less. Many 800 MHz B/ILT incumbents would be relocated to 700 or 900 MHz bands.

- Desense: Without new public safety filters, moving the public safety allocation to the lower portion of the band will have no effect on desense. Consequently, desense will continue as one of the two predominant sources of interference.
- Intermodulation: Compared to the present allocation, somewhat fewer intermod products will fall in the Nextel public safety allocation. However, the combination of a lack of filtering in the public safety radios, together with the large number of interfering CMRS signals, will still result in a significant number of intermod products falling in the 851 – 861 MHz public safety block.
- Out-of-band emissions: The Nextel plans move public safety away from cellular A block, but it is still immediately adjacent to the low-site digital SMR allocation at 861 – 869 MHz, although possibly separated by a guard band of unknown extent.
- Disruption: The Nextel plan requires massive relocations, requiring new equipment to relocate B/ILT users to 900 and 700 MHz. The 700 MHz equipment is not even commercially available at this time.

#### *5.4 FCC*

Under the FCC's proposal, lower 800 MHz public safety licensees in the interleaved bands would be moved to contiguous spectrum at 809.75-811.5 MHz and 854.75-856.5 MHz. They would operate next to B/ILT licensees at 811.5-814 MHz and 856.6-859 MHz, which would provide a buffer from interfering digital SMR systems. However, the current upper 800 MHz public safety allocation at 821-824 MHz and 866-869 MHz would remain unchanged and adjacent to potentially interfering digital SMR at 816-821 MHz and 861-866 MHz.

- Desense: Without new public safety filters, CMRS operations still remain within the public safety radio passband. With public safety channels at both the low end and the high end of the band, even future generation public safety radios would not be able to take advantage of improved filtering, since both ends of the bands still need to be passed.
- Intermodulation: With the NPSPAC allocation remaining the same, there will be no reduction of intermod within these channels. Aggregating the other public safety channels to the low end of the band may result in a slight reduction in intermod interference there. With public safety channels at both the low end and the high end of the band, even future generation public safety radios would not be able to take advantage of improved filtering, since both ends of the bands still need to be passed.
- Out-of-band emissions: The new aggregated public safety channels at the low end would experience a reduction in out-of-band interference. The NPSPAC channels, which remain the same as today, would see no improvement.
- Disruption: The FCC plan requires a smaller number of retunes and frequency swaps than the Nextel or NAM proposals.

#### *5.5 NAM*

Under the NAM Proposal, three separate but adjacent contiguous channel blocks would be reserved as follows: (i) 10 MHz for public safety at 806-811 MHz and 851-856 MHz; (ii) 10 MHz for conventional SMR and B/ILT at 811-816 MHz and 856-861 MHz; and (iii) 16 MHz for digital SMR (i.e., Nextel) at 816-824 MHz and 861-869 MHz.

- Desense: Without new public safety filters, CMRS operations still remain within the public safety radio passband. Consequently, the NAM proposal will not alleviate desense.
- Intermodulation: Compared to the present allocation, somewhat fewer intermod products will fall in the NAM public safety allocation. However, the combination of a lack of filtering in the public safety radios, together with the large number of interfering Nextel signals, and to a lesser extent other CMRS signals, will still result in a significant number of intermod products still falling in the new public safety block.
- Out-of-band emissions: The new public safety block is removed from both the cellular and SMR bands. Lower out-of-band emissions will be present in the new public safety allocation, although these emissions are only a small contributor to the interference problem.
- Disruption: NAM requires significant relocations and new equipment, but does not require relocations to new bands.

## **6. Summary and Recommendations**

This document summarizes the experiences of the WG with regard to reported public safety interference. It provides a summary of technical data related to interference. It also discusses the various 800 MHz rebanding proposals, and their predicted impact on reducing interference.

The discussions and technical data presented in this document lead to the clear conclusion that, by itself, *rebanding 800 MHz will not produce any significant reduction in interference to public safety communications*. Rebanding 800 MHz will only result in reduced interference if the manufacturers of public safety radios redesign their systems to take specific advantage of the new allocations. It is the WG's understanding that the lifespan of public safety radios is typically 15 years or more, requiring until 2017 or beyond before public safety will be able to take advantage of new radio technology. Even with new hardware, public safety radios will continue to have trouble operating in the 800 MHz band, as other 800 MHz operators build out their systems and compete for valuable spectrum. Further, by creating radios that are specific to the new allocation, the public safety radio performance may suffer for other reasons (higher filter insertion loss), and public safety will have no ability to expand spectrum capacity in the future.

For all of these reasons, it is the conclusion of the WG that the only clear path to mitigation of interference is to relocate public safety to a new band entirely. For several reasons, the upper 700 MHz band is ideal:

- A public safety allocation already exists at 700 MHz.

- Additional upper 700 MHz spectrum (30 MHz that has yet to be auctioned) is available for possible reallocation to public safety, providing them with room for future expansion of spectrum capacity.
- Current incumbents in 700 MHz, not yet in operation, are limited to the “Guard Band” licensees, which are not allowed to operate cellular-like systems and which have very tight out-of-band emissions limits already in place.
- The timescale for availability of 700 MHz spectrum (end of 2006) is over ten years sooner than awaiting for general penetration of new “rebanded” 800 MHz radios.
- Auction of current 800 MHz public safety spectrum could provide expansion spectrum for 800 MHz incumbents such as Business, Industrial/Land Transportation, SMR, and cellular, and the revenues from the auction could be used to relocate public safety to 700 MHz.

Although the WG believes that, in the long term, relocation of public safety to 700 MHz is the only option that will substantially reduce public safety interference, in the near-term it urges public safety, Nextel, and the WG member companies to continue to follow the APCO “Best Practices Guide” when performing system engineering and when dealing with cases of reported interference to public safety systems.

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